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SUBJECT: Remote Maintenance Experimental Work on a Reactor System Pump

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FROM: W. B. McDonald, C. K. McGlothlan, E. Storto

Abstract

The information presented is an experimentally determined evaluation of standard remote handling equipment applied to the problems associated with remote maintenance of a typical reactor system component.

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Remote Maintenance Experimental Work on a Reactor System Pump

Table of Contents

1.0 Introduction

A molten salt nuclear power reactor system intended for application to the generation of commercially distributed electricity must, in order to be competitive with conventional central station plants, be capable of operating for a period of 20 years without major overhaul. Preventive maintenance and replacement of faulty components must be performed with minimum interruption to power operation, and due to a high level of radioactivity, maintenance and repair operations on the reactor primary system must be conducted remotely.

The test described in this report was devised as an approach to the solution of a typical remote maintenance problem of the type likely to be encountered in the operation of a molten salt power reactor system. Its objectives were:

(a) To evaluate a standard model commercially available motor-operated mechanical arm manipulator as a reactor system remote maintenance tool.

(b) To determine the character and extent of special fixtures and tools required to perform a typical remote maintenance operation with the standard manipulator.

(c) To gain insight to the design criteria which should be applied to reactor system components, to make them suitable for remote maintenance.

(d) To gain insight to the magnitude of effort required to establish a workable remote maintenance procedure, and to train an operator to perform a maintenance task using the standard manipulator, special tools and fixtures, and special procedure.

(e) To determine the feasibility of using closed circuit television to view and control remote maintenance operations.

2.0 Summary and Conclusions

A 3-1/2" NaK pump (Model PK, see Fig. 11) was set up as a test dummy in an uncontaminated hot cell, where a new mechanical arm manipulator (GM Model E-3) was available. Fixtures were designed and added to the pump bowl to permit making and breaking all service lines en bloc, by the manipulator. Other fixtures and tools were designed and fabricated as required for the removal and replacement of the pump rotary element by the manipulator. A procedure was written for the complete operation, and a technician with no previous manipulator experience was assigned to perform the work.

After becoming familiar with the operating procedure and gaining facility using the equipment by direct observation through the cell window, the technician was required to repeat the procedure using indirect observation by closed circuit television.

Results of the test show that commercially available equipment can be used, with a few simple tools and fixtures, to perform a typical reactor system maintenance operation. It was also demonstrated that a good technician can, with no special training, rapidly acquire facility in using the manipulator for maintenance operations.

No radical changes in design principles are indicated to make reactor system components suitable for remote manipulation. The main considerations are accessibility of parts, piloted fits, and en bloc service connections. When designing a component, it should be kept in mind that operations which can be easily performed by hand become difficult when performed by remote manipulation, and the effort required to design a component requiring minimum handling for maintenance will be very worthwhile. The component and the tools for its maintenance should be designed for the particular manipulator to be used in the installation, and the component and its installation should be designed wherever possible for maintenance from the overhead position.

It is possible, with proper lighting, to apply commercially available closed circuit television equipment to control-viewing of remote maintenance operations. Two circuits are necessary, to provide rectilinear vision in lieu of normal depth perception. The use of TV for such applications will require the perfection of radiation-resistant equipment, now under development.

3.0 Discussion

3.1 Test Facility

The facility used was an uncontaminated hot cell (see Fig. 1) in the newly constructed ORNL Fission Product Pilot Plant and was borrowed from the Radioisotope Production Department until required for their occupancy, a period of six weeks. The cell floor is built in two levels, one at building floor level, and one at window level. The test pump was mounted at floor level, which brought the rotary element near window height. Special tools and fixtures were stored on the upper level. Service outlets for electricity and compressed air were available. A General Mills Model E-3 mechanical arm manipulator on a traveling bridge mount covered the work area (see Fig. 2), and the services of an overhead crane were available through a hatch in the cell roof.

Several Argonne Model 8 master-slave units were also available, and their versatility would have been appreciated in many of the test operations; the nature of their construction, however, restricts their movements to a small area, and it was considered unrealistic to use them as tools for maintenance on a component representing part of a large system. A remotely controlled, servo-operated master-slave unit is now under development by Borge-Warner Company, and if this proves successful, could later be adapted to remote maintenance use.

Direct viewing through a cell window (Figs. 3 and 4) was used in working out the test procedure. This procedure was later repeated, using a Dage closed circuit television system for viewing (Figs. 5 and 6).

3.2 Test Article

A pump rotary element consisting of impeller, shaft, bearings, and seals will probably be the only moving part in a molten salt power reactor primary fluid system. Since failure of this component would be likely during a 20 year operating period, it was decided that its removal and replacement would constitute a typical maintenance operation.

An available Model PK pump was selected for the test. It is a vertical shaft, horizontal discharge, sump type pump. (See Fig. 7) The only modification made for test purposes was to attach a frame to the pump bowl, for support of the en bloc service line connections (See Fig. 8).

3.3 Tools and Fixtures

Tooling was relatively simple and inexpensive. It consisted of the following items: (See Fig. 9. The numbers on the figure correspond to those below.)

3.3.1 Pneumatic impact wrench

A standard 1/2" drive Thor Model 24L wrench was used, with a shop-made adapter for attachment to the manipulator hook, and a factory-made accessory for torque control. Air supply to the wrench was regulated by the operating technician, outside the cell. The impact wrench was proven to be effective for fast nut running, and provided all power necessary to tighten or loosen nuts or bolts. Torque control, however, was found to be erratic whether controlled from outside the cell by a supply pressure regulator, or by the wrench torque attachment. Torque tests were run using various combinations of air pressure and operating time. Results are given in tabular form in the Appendix, Item 1. For applications where accurate torquing of bolts is necessary, a more positive method of torque control must be devised.

3.3.2 Hook-and-eye socket wrench

Special wrench with 1-1/8" socket to be driven by the manipulator hook. (See Fig. 9)

3.3.3 Hook-and-eye socket wrench

Special wrench with 1-5/16" socket to be driven by the manipulator hook. (See Fig. 9)

3.3.4 Socket, 3/4", for impact wrench. (See Fig. 9)

3.3.5 Socket, 1-1/8", for impact wrench. (See Fig. 9)

3.3.6 Counterweight assembly with three lead bricks. (See Fig. 9)

3.3.7 Eye bolt for lifting pump rotary element. (See Fig. 9)

3.3.8 Shaft locking plate for use in installing eye bolt in pump rotary element. (See Fig. 9)

3.3.9 Bolt tray for storing cap screws and bolts. (See Fig. 9)

3.3.10 Jig for remotely removing hook from General Mills manipulator. (See Fig. 9)

3.3.11 Jig for remotely removing fingers from General Mills manipulator (with fingers in jig). (See Fig. 9)

3.3.12 Feeler gages for checking gap between pump flanges. (See Fig. 9)

3.3.13 Jack bolts for pump flanges. (The jack bolts, threads and all other threaded connectors were coated with molybdenum disulphide for lubrication.)

3.4 Test Procedure

Test work on the removal and replacement of the pump rotary element was conducted in two phases. The first phase may be described as a series of cut-and-try experiments, in which the various operations involved were individually diagnosed, and the necessary manipulator movements and tooling worked out. The second phase consisted of integrating the individual operations into a continuous procedure, represented by a check list. (Appendix, Items 2 and 3.)

The procedure thus developed was then practiced by the technician operator to gain facility with the equipment. A movie was made of the complete procedure, for time and motion study reference.

After the operator had become proficient in the procedure, a closed circuit television system was set up and the procedure was again attempted with no direct viewing. It was found that lack of depth perception, inadequate lighting, and rather course picture resolution imposed a severe handicap. Certain operations were performed successfully, but with great difficulty. The indications are very strong, however, that with a pair of camera-monitor circuits to give rectilinear or stero vision, and with proper lighting, lens quality, and circuit adjustment, it will be possible to conduct remote maintenance operations with television viewing.

Details of the television experiment are given in the Appendix, Item 4.

3.5 Maintenance on General Mills Manipulator

The manipulator, although designed for installation in remote and contaminated areas, must be maintained in a manner similar to all machines. The maintenance performed on this manipulator during the 6 weeks of the test are listed in the Appendix, Item 5.

3.6 Log of Events and Recommendations for Improving Remote Removal of Pump.

See Appendix, Item 6.

Appendix - Item 1

Typical Torque Results Obtained with the Impact Wrench and Checked with a Hand Operated Torque Wrench

a. By varying the air pressure and using a 1-5/16" socket on one cap screw:

Air Pressure (psig)	Torque (1st attempt) (ft-lbs)	Torque (2nd attempt) (ft-lbs)	Time
90	110	65	Variable
80	60	55	"
70	40	40	"
65		25	"
60	30	10	"
50	5*	5*	"

* No impact by wrench

b. By maintaining the air pressure and time constant and using a 1-5/16" socket on one cap screw:

Air Pressure (psig)	Time (sec)	Torque (ft-lbs)
90	10	110
90	10	70
90	10	70
90	10	90
90	10	100
90	10	80
90	10	70
90	5	65
90	5	70

c. By maintaining the air pressure and time constant and using a 1-5/16" socket on two cap screws. Torque varied by control on impact wrench.

Air Pressure (psig)	Torque Regulator Setting	Torque Obtained (ft-lbs) No.1 Screw	Torque Obtained (ft-lbs) No.2 Screw	Time (sec)
90	4	45	45	10
90	5	50	50	10
90	5	50	50	10
90	5	50	60	10
90	5	55	50	10
90	5	50	50	10
90	5	50	60	10
90	5	50	60	10
90	5	50	50	10
90	6	55	50	10
90	6	50	60	10
90	6	55	55	10
90	6	55	60	10
90	7	65	70	10
90	7	70	65	10
90	7	65	65	10
90	7	60	65	10
90	8	65	75	10
90	8	65	70	10
90	8	65	70	10
90	8	65	70	10
90	9	65	75	10
90	9	65	70	10
90	9	70	65	10
90	9	70	65	10

Appendix - Item 2

PK Pump Remote Disassembly Check List

Operation	Tool
1. Set rotation of impact wrench to unscrew and adjust torque to 40 ft-lbs.	GM finger. Set air pressure at 65 psi outside cell.
2. Attach 3/4" socket to impact wrench	GM finger, 3/4" socket, socket lock clip & impact wrench jig
3. Replace GM finger with GM hook	Hook changing bracket and finger changing bracket
4. Attach impact wrench	GM hook, impact wrench jig
5. Unscrew (15) header block cap screws in numerical order	GM hook and impact wrench
6. Remove impact wrench from GM hook	Impact wrench jig
7. Replace GM hook with GM finger	Hook changing bracket and finger changing bracket
8. Replace 3/4" socket on impact wrench with 1-5/16" socket	GM finger, socket lock clip, 1-5/16" socket, impact wrench jig
9. Insert jack bolts in upper pump flange	4 each 3/4" cap screws and GM finger
10. Replace GM finger with GM hook	Hook changing bracket and finger changing bracket
11. Attach hook-and-eye tool to hook	1-1/8" hook-and-eye tool, GM hook and bench
12. Screw (4) jack bolts in snug (10 - 30 ft-lbs.)	GM hook, 1-1/8" eye bolt tool
13. Remove hook-and-eye tool.	1-1/8" hook-and-eye tool, GM hook and bench
14. Attach impact wrench	GM hook and impact wrench jig
15. Unscrew (12) cap screws in pump flange in numerical order	GM hook and impact wrench
16. Remove impact wrench	GM hook, impact wrench jig
17. Attach hook-and-eye tool to GM hook	1-1/8" hook-and-eye tool, GM hook and bench
18. Tighten each jack bolt 1/2 turn until gap between flanges is .255"	1-1/8" hook-and-eye tool and GM hook

Operation	Tool
19. Remove hook-and-eye tool	Bench, GM hook
20. Replace GM hook with GM fingers	Hook changing bracket and finger changing bracket
21. Secure spacer gage in GM finger	.255 inch spacer gage on bench and GM finger
22. Check gap between flanges on pump	Spacer gage, GM finger
23. Remove spacer gage	GM finger, bench
24. Attach pump shaft locking plate	GM finger, bench
25. Insert cap screws in counterweight	GM fingers, 2 each 3/4" cap screws
26. Remove 3 cap screws from pump	GM fingers, 3 each 7/8" cap screws to bolt tray
27. Replace GM finger with GM hook	Hook changing bracket and finger changing bracket
27a. Repeat operation No. 17	
27b. Unscrew 2 jack bolts	1-1/8" eye bolt tool and GM hook
27c. Remove hook-and-eye tool	Bench, GM hook
27d. Replace GM hook with GM finger	Hook changing bracket and finger changing bracket
27e. Remove 2 cap screws	GM finger, 2 each 3/4" cap screws to bolt tray
27f. Repeat operation No. 27	
28. Lift counterweight into position	GM hook, counterweight from bench
29. Attach hook-and-eye tool to GM hook	1-1/8" hook-and-eye tool from bench and GM hook
30. Tighten (2) counterweight bolts to 5 - 10 ft-lb	1-1/8" hook-and-eye tool and GM hook
31. Remove hook-and-eye tool from hook	Bench, GM hook
32. Insert eye bolt in pump rotary element	GM hook, and eye bolt from bench
33. Lift pump rotary assembly out of pump bowl	Overhead bridge crane and wire rope choker, GM hook

Operation	Tool
34. Set pump rotary assembly on stand on second floor cell	Special pump stand
35. Replace GM hook with GM finger	Hook and changing bracket and finger changing bracket
36. Remove solid "O" ring gasket from pump lower flange and lay on bench	GM finger
37. Remove solid copper gasket from header block and lay on bench	GM finger

Appendix - Item 3

PK Pump Remote Assembly Check List

	Operation	Tool
1.	Install 15 cap screws in upper half of header block	By hand outside cell
2.	Install 9 of 12 cap screws in pump rotary element flange	By hand outside cell
3.	Install counterweight on pump rotary element (torque cap screws at 10 ft-lbs)	By hand outside cell, 1-1/8" socket and handle
4.	Install lifting eye bolt in rotary element	By hand outside cell
5.	Install small "O" ring gasket on pump rotary element	By hand outside cell
6.	Plumb pump rotary element and header block assembly by moving counterweight	Level. Adjust by hand outside cell
7.	Lock pump shaft in position	Install lock plate by hand outside cell
8.	Install flat gasket on lower header block	GM finger
9.	Install "O" ring gasket in pump bowl flange	GM finger
10.	Replace GM finger with GM hook	Hook changing bracket and finger changing bracket
11.	Lower pump rotary element into bowl assembly	By overhead bridge crane
12.	Attach hook-and-eye tool to GM hook	GM hook, 1-1/8" hook-and-eye tool from bench
13.	Unscrew counterweight cap screws (2 each - 3/4" cap screws)	GM hook, hook-and-eye tool
14.	Remove hook-and-eye tool	GM hook and bench
15.	Replace GM hook with GM finger	Hook changing bracket and finger changing bracket
16.	Remove 2 counterweight bolts	GM fingers, bolt tray

Operation	Tool
17. Repeat operation No. 10	
18. Remove counterweight assembly	GM hook and bench
19. Replace GM hook with GM finger	Hook changing bracket and finger changing bracket
20. Install 3 pump flange cap screws	GM finger, 3 each 7/8" cap screws from bolt tray
21. Secure "No go" feeler gage to GM finger	Use .265 inch feeler gage from bench
22. Check flange gap every 120°	Feeler gage & GM finger
23. Remove feeler gage from GM finger	GM finger to bench
24. Secure "go" feeler gage to GM finger	Use .260 inch feeler gage from bench
25. Check pump flange gap	Feeler gage & GM finger
26. Remove feeler gage from GM finger	GM finger to bench
27. Replace GM finger with GM hook	Hook changing bracket and finger changing bracket
28. Attach hook-and-eye tool to GM hook	GM hook, 1-5/16" hook-and-eye tool from bench
29. Tighten all pump cap screws down snug alternating every 180° (5 - 10 ft-lbs of torque)	GM hook and hook-and-eye tool
30. Remove hook-and-eye tool	GM hook to bench
31. Replace GM hook with GM fingers	Hook changing bracket and finger changing bracket
32. Secure "no go" feeler gage to GM finger	Use .260 inch feeler gage
33. Check flange gap every 120°	GM fingers & feeler gage
34. Remove feeler gage from GM finger	GM finger to bench
35. Secure "go" feeler gage to GM finger	Use .255 inch feeler gage from bench
36. Check pump flange gap	Feeler gage to GM finger
37. Remove feeler gage from GM finger	GM finger to bench
38. Set rotation of impact wrench	GM fingers and impact wrench jig
39. Replace GM finger with GM hook	Hook changing bracket and finger changing bracket

Operation	Tool
40. Attach impact wrench	GM hook, 1-5/16" socket and impact wrench jig
41. Tighten all pump bolts for 10 seconds alternating every 180° to 50 - 75 ft-lbs of torque	GM hook and impact wrench Set air pressure at 85 lbs outside cell
42. Remove impact wrench	GM hook and impact wrench jig
43. Replace GM hook with GM fingers	Hook changing bracket and finger changing bracket
44. Secure "no go" feeler gage to GM finger	Use .255 inch feeler gage
45. Check pump flange gap	Spacer gage
46. Remove feeler gage from GM finger	GM finger to bench
47. Secure "go" feeler gage to GM finger	Use .250 inch feeler gage
48. Check pump flange gap	GM finger to feeler gage
49. Remove feeler gage from GM finger	GM finger to bench
50. Replace 1-5/16" socket with 3/4" socket on impact wrench	GM finger, 3/4" socket lock clip and impact wrench jig
51. Set torque to 5 - 15 ft-lbs on impact wrench	Set air pressure at 50 psi outside cell
52. Replace GM fingers with GM hook	Hook changing bracket and finger changing bracket
53. Attach impact wrench	GM hook and impact wrench jig
54. Tighten all header block cap screws by alternating between screws	GM hook and impact wrench
55. Repeat operation 54 except use 30 ft-lbs of torque on impact wrench	Set air pressure at 75 psi outside cell
56. Remove impact wrench	GM hook and impact wrench jig
57. Remove eye bolt in rotary element of pump	GM hook to bench
58. Remove shaft locking plate	GM hook to bench

Appendix - Item 4

Operation by Television

After the pump had been successfully disassembled and assembled three times remotely by viewing the various operations through the cell window, a closed circuit television system was borrowed from the Reactor Experimental Engineering Division for use in viewing the same disassembly and assembly operations. The television system was used only a few days; however, knowledge was gained on its capabilities and limitations. Only a few of the pump remote disassembly and assembly operations were performed using the television due to the short time available.

The closed television system consisted of (a) one forced air-cooled Dage "Cyclops" camera approximately 3 inches in diameter and 18 inches long with a single lens, mounted inside the cell; (b) one Dage camera control cabinet including a 3-inch monitor screen, mounted outside the cell; (c) one 17" Conrac view screen, mounted outside the cell.

The camera was mounted in two locations in the cell in an effort to obtain the best viewing vantage point. One of the positions consisted of locating the camera on a fixed tripod on the window level of the cell and directing it at the particular operation on the pump. The camera was mounted approximately two feet higher in elevation than the pump. In the other position the camera was mounted on the General Mills manipulator upper housing approximately 8 feet higher in elevation than the pump and moved as the manipulator bridge moved. The camera was directed down to the tool on the manipulator and therefore moved to different locations as the manipulator moved. There are advantages and disadvantages to both methods of mounting the camera, and are listed below.

1. <u>Fixed Location</u>

<u>Advantages</u>

a. Good vertical alignment of tool at 0° azimuth

b. Control cable from camera to monitor and air line to camera are fixed and do not have to be moved after initial installation

<u>Disadvantages</u>

a. Poor vertical alignment of tool at 90° azimuth

b. No 3-D effect

c. Camera with a single lens for detail work will require moving for each manipulator

c. Elevation of tool on manipulator with respect to pump can be easily observed.

d. Slightly better detailed picture on 17" view screen as compared with GM camera location.

operation, or if a wide angle lens is used the picture is not sharp enough to work by

2. <u>Movable Location</u> (Located on GM Manipulator)

<u>Advantages</u>

a. Good vertical alignment of tool at any azimuth.

b. In general, the camera can move with the manipulator and view the various detail operations on the pump, etc., without relocating the camera after each operation.

a. Poor observation of the tool elevation with respect to the pump.

b. Camera control cable and air line have to be moved around in the cell as the manipulator moves.

c. No 3-D effect

<u>Recommendations & Requirements for Installing Closed Circuit Television for Use in Viewing Remote Reactor Maintenance Operations</u>

1. Camera and lenses should be radiation resistant.
2. Camera should withstand 250°F temperatures.
3. Camera should be equipped with a remotely controlled 3 or 4 lens turret that will permit remote selection of any of the lenses with remote adjustment of aperture and focus. In addition, the camera should have a remotely controlled pan and tilt mount for aiming the camera vertically and horizontally.
4. A minimum of two cameras and view screens are required for depth perception.
5. Cameras should be mounted semi-permanently around the reactor such that they can be picked up with an overhead crane or manipulator and moved to a new location. Provide suitable openings in the reactor shielding to permit inserting and removing the cameras for maintenance operations.
6. Cameras should be mounted level or slightly above the location where the work of the manipulator is being performed.

7. One of the two cameras should be mounted such that an overall picture of the manipulator and reactor can be obtained, if necessary, to prevent a collision of the manipulator with the reactor and auxiliary equipment when moving the manipulator into position.
8. Both of the cameras, 90° apart, should be capable of being directed on the work location to follow the detail operation of the manipulator.
9. Color TV or 3-D TV is not necessary to perform the operations.
10. When using a General Mills manipulator, the TV cameras should be mounted parallel and perpendicular to the manipulator bridge, if possible, in order to coordinate the movements of the control levers on the manipulator with respect to the picture on television.
11. Lighting of the reactor components should be from 30 - 50 foot-candles.

Appendix - Item 5

Maintenance on GM Manipulator

1. Vent plug in hoisting gear box was originally installed in wrong hole and oil dripping developed after several hours of operation. This condition got worse as the temperature of the cell increased. After about 3 days of operation, the GM was shut down and an investigation by a mechanic disclosed the incorrect installation of the vent plug and that the gear box was almost dry. The entire manipulator was re-lubricated as a preventive maintenance measure. Down time - 8 hours.
2. During the fourth week of operation, the grip force indicator did not register the correct force before the ball indent type slip clutch would slip. It was thought that the clutch was slipping before the maximum grip force was exerted. In order to correct for this it was necessary to add .020 inch in shims to the clutch assembly. This required that the lower gear box on the GM arm be disassembled. Down time - 12 hours.
3. About 4 hours of operation after the clutch was repaired the same condition developed. The grip force indicator would not indicate the correct grip force before the clutch slipped. This time the mechanics found that the sensing coil that obtains the grip force of the fingers in the manipulators was not operating properly. An effort was made to repair it but it was not successful without a new coil. At this time the factory was called and they agreed to install a new revised clutch assembly and force indicator in the manipulator free of charge as soon as it could be sent back to the factory. The manipulator was reassembled for use on this job; however, it was necessary to guess at the grip force during operation. The new clutch can be adjusted without disassembling the forearm gear box. Down time - 8 hours.
4. During the fourth week of operation, a condition existed such that the three section telescoping boom would not raise the last 5 inches of travel. The two sections of the telescoping boom that would not raise were partially disassembled with the ball bearing between the two telescoping tubes removed. No visible signs of trouble were observed. The

balls were reinstalled in the telescoping tubes and the entire mechanism reassembled. The manipulator operated in the correct manner even though no repairs were made. Down time - 4 hours.

Total Operating Time - Approximately 75 hours over a period of 6 weeks.

Appendix - Item 6

Log of Events and Recommendations For Improving Maintainability of Pump

1. Edges of lock plates part number A-2906 (ORNL drawing F-2-02-054-2882) extended past edge of rotary element approximately 1/32" - 1/16" and caused scoring of the pump bowl wall during first disassembly. These sharp edges were filed off flush with the edge of the rotary element.
2. The rotation of the pump shaft was checked before the first disassembly operation and a slight rubbing was observed. This did not occur again after the next 2 assembly operations.
3. During the first disassembly of the pump, the studs and nuts both came out together and when the stud came out,the nut was unscrewed on the stud. This condition was not satisfactory and as a result there were 24 pieces of hardware to handle remotely. To eliminate 12 of these pieces, cap screws were used in place of the studs and nuts.
4. It is suggested that the cap screws both in the pump and header block be softer than the stationary part they are being threaded into. This will prevent damage to the threads in the stationary element. In case the cap screws are cross threaded they can be replaced with new ones and no damage will have been done to the stationary element.
5. All gaskets should be designed such that they can be assembled on the rotary element before it is installed in the pump bowl. In addition, during the disassembly operation, the gaskets should remain attached to the rotary element so that they will come out with the rotary element and not have to be taken out separately.
6. All cap screws, bolts, etc., should be, where possible, installed such that they can be removed and replaced from directly overhead.
7. It is suggested that all auxiliary gas and oil lines to the pump be connected by means of a header block and not have individual pipe connections for each line.
8. Cap screws should be designed with tapered noses and the threads removed for a short distance back from the end of the screw so they stand upright in their holes without leaning or falling out. (See Fig. 10)

9. The pump should be self guiding into the pump bowl for ease of assembly and should seat within a few thousandths of an inch before it is released by the overhead crane.
10. It should not be necessary for the jack bolts to do anything except break the seal between pump rotary element and the pump bowl. As soon as this seal is broken the crane should be able to lift the rotary element out of the bowl without any binding or restriction of any kind. A few thousandths of an inch movement of the jack bolts should be sufficient to break the seal.
11. A positive drive is required to tighten and loosen the various cap screws. This drive must have a variable speed of 2 - 15 RPM and develop a variable torque from 0 - 300 ft-lbs. The torque should be adjustable to ± 5%. The drive should stop or indicate when the preset torque is reached. The drive should be easily attached and detached remotely to the GM manipulator.

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6.0 Future Considerations

The information and practice gained in the performance of the reported test will be applied in the design of corollary tests. These tests will define and resolve problems in remote viewing, remote welding, system component design for remote handling, remote joining of piping elements, and system layout for remote maintenance.

Some work is now in progress in all of the test categories enumerated above, and it is intended that a report will be issued as soon as possible after the completion of a significant phase of any test.

Approved by W. B. McDonald
W. B. McDonald

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40. H. W. Hoffman
41. A. Hollaender
42. W. S. Hornbaker
43. A. S. Householder
44. W. H. Jordan
45. P. R. Kasten
46. G. W. Keilholtz
47. M. T. Kelley
48. B. Kinyon
49. R. B. Korsmeyer
50. E. Lamb
51. J. A. Lane
52. W. H. Lewis
53. R. B. Lindauer
54. R. S. Livingston
55. R. N. Lyon
56. H. G. MacPherson
57. W. D. Manly
58. L. A. Mann
59. W. B. McDonald
60. C. K. McGlothlan
61. J. R. McNally
62. A. J. Miller
63. K. Z. Morgan
64. E. J. Murphy
65. J. P. Murray
64. M. L. Nelson
65. E. W. Parrish
66. P. Patriarca
67. A. M. Perry
68. M. Ramsey
69. F. Ring
70. A. F. Rupp
71. H. W. Savage
72. A. W. Savolainen
73. W. F. Schaffer
74. E. H. Seidler (Westinghouse)
75. D. M. Shepherd
76. E. D. Shipley
77. O. Sisman
78. M. J. Skinner
79. A. H. Snell
80. I. Spiewak
81. E. Storto
82. J. A. Swartout
83. A. Taboada
84. E. H. Taylor
85. D. S. Toomb
86. D. B. Trauger
87. W. E. Unger
88. A. M. Weinberg
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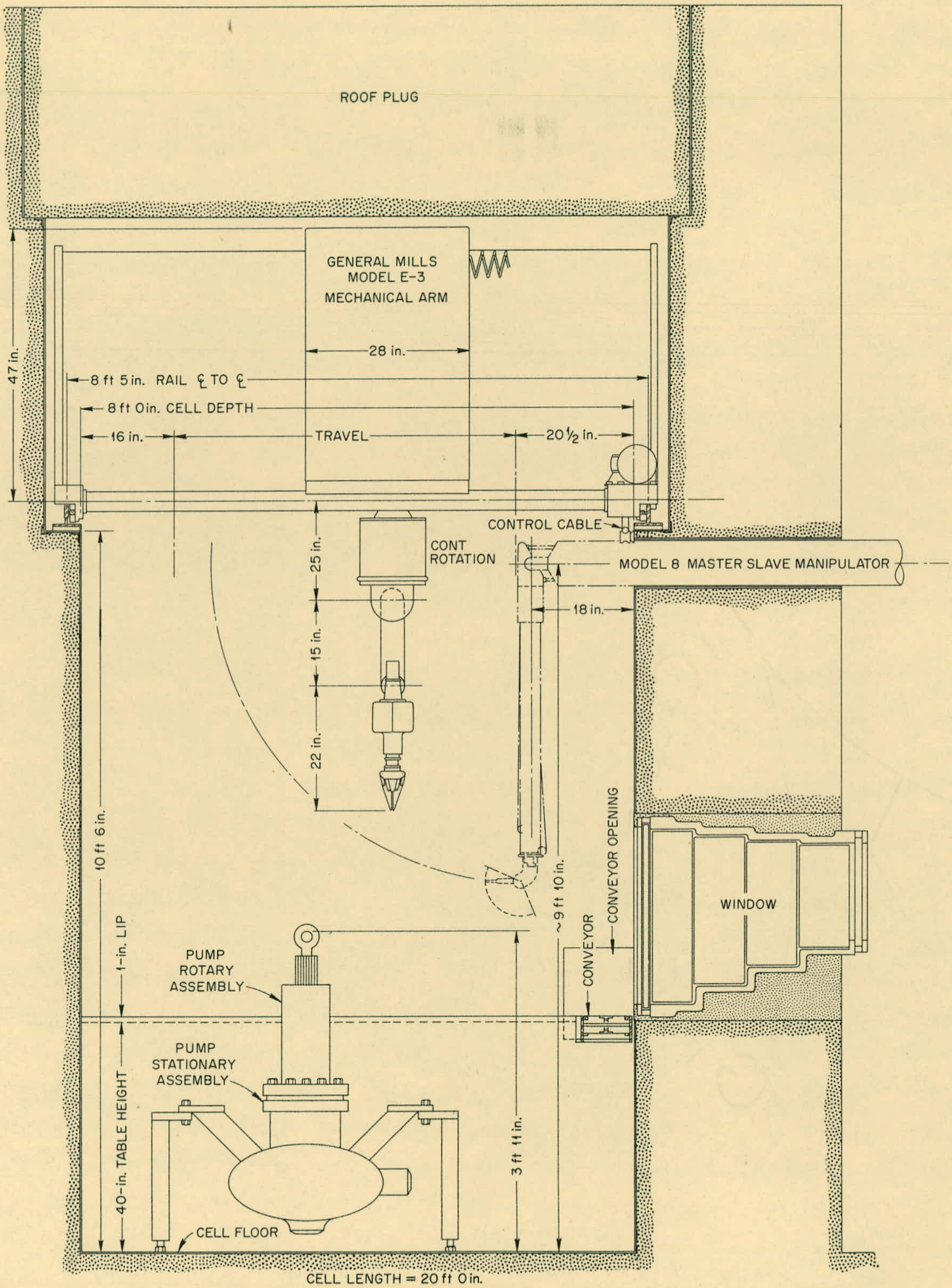

Figure 1 Cell Layout of Mechanical Arm and PK Pump

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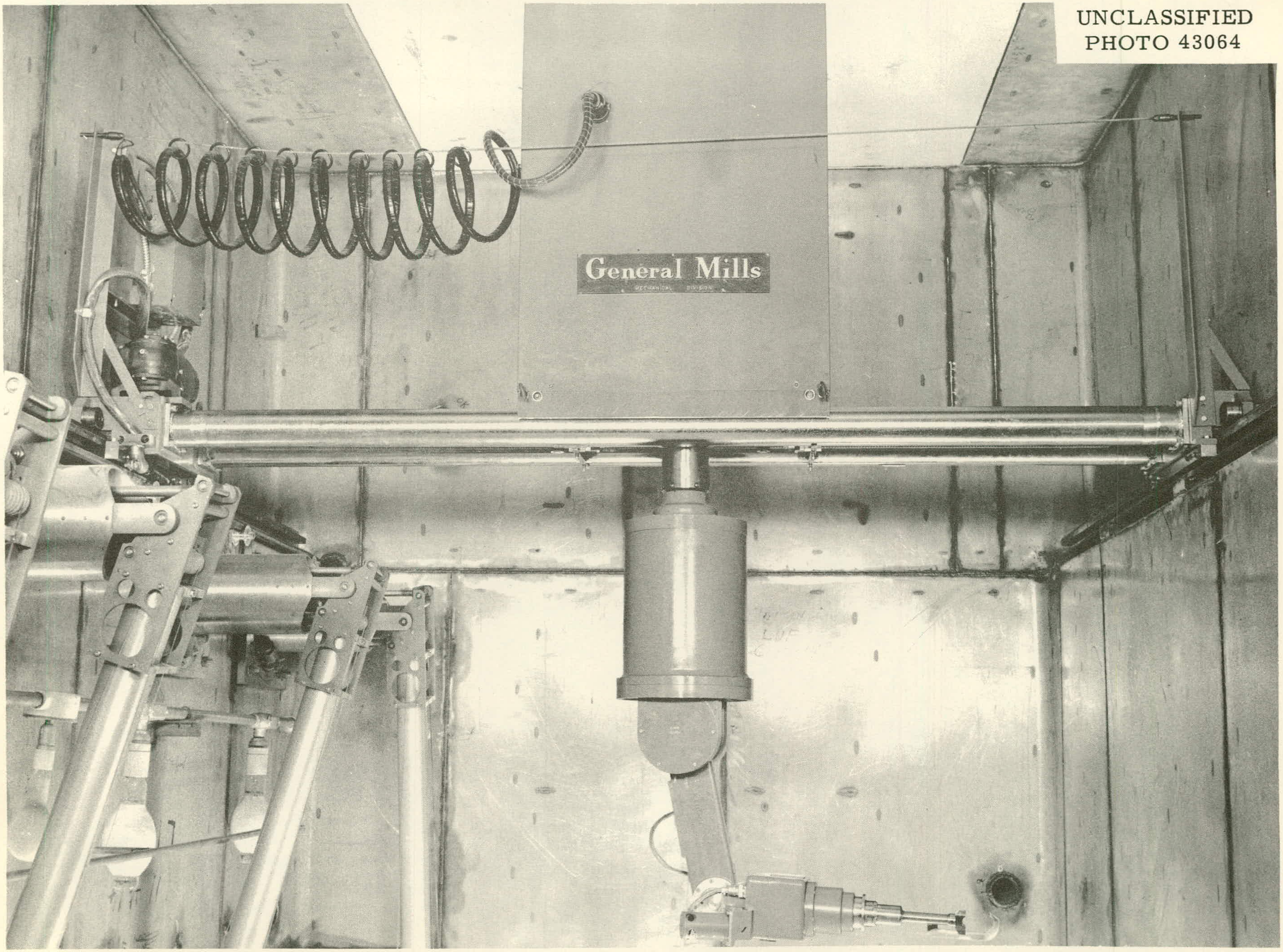

Figure 2 General Mills Mechanical Arm Manipulator

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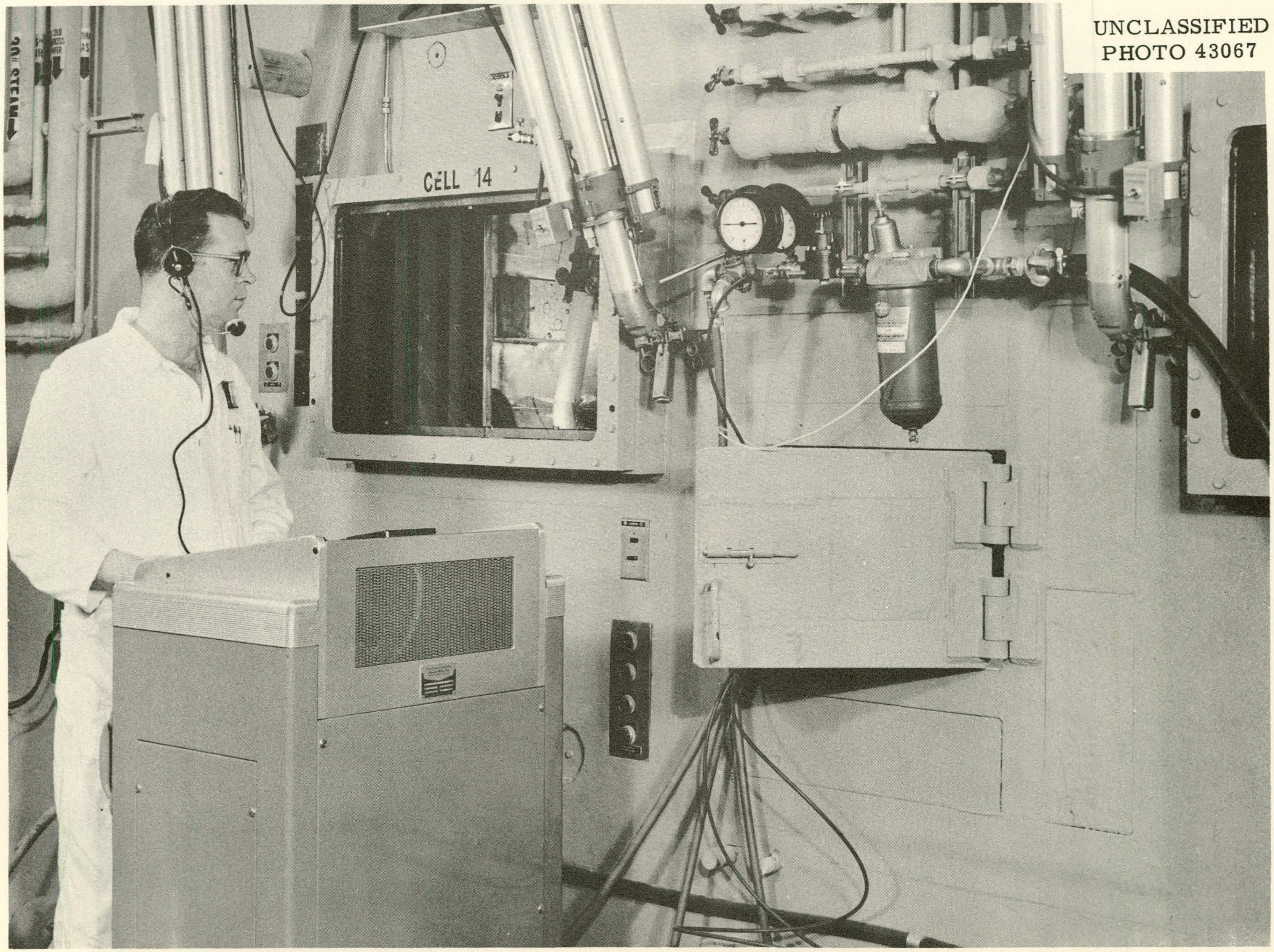

Figure 3 Viewing Pump Through Cell Window

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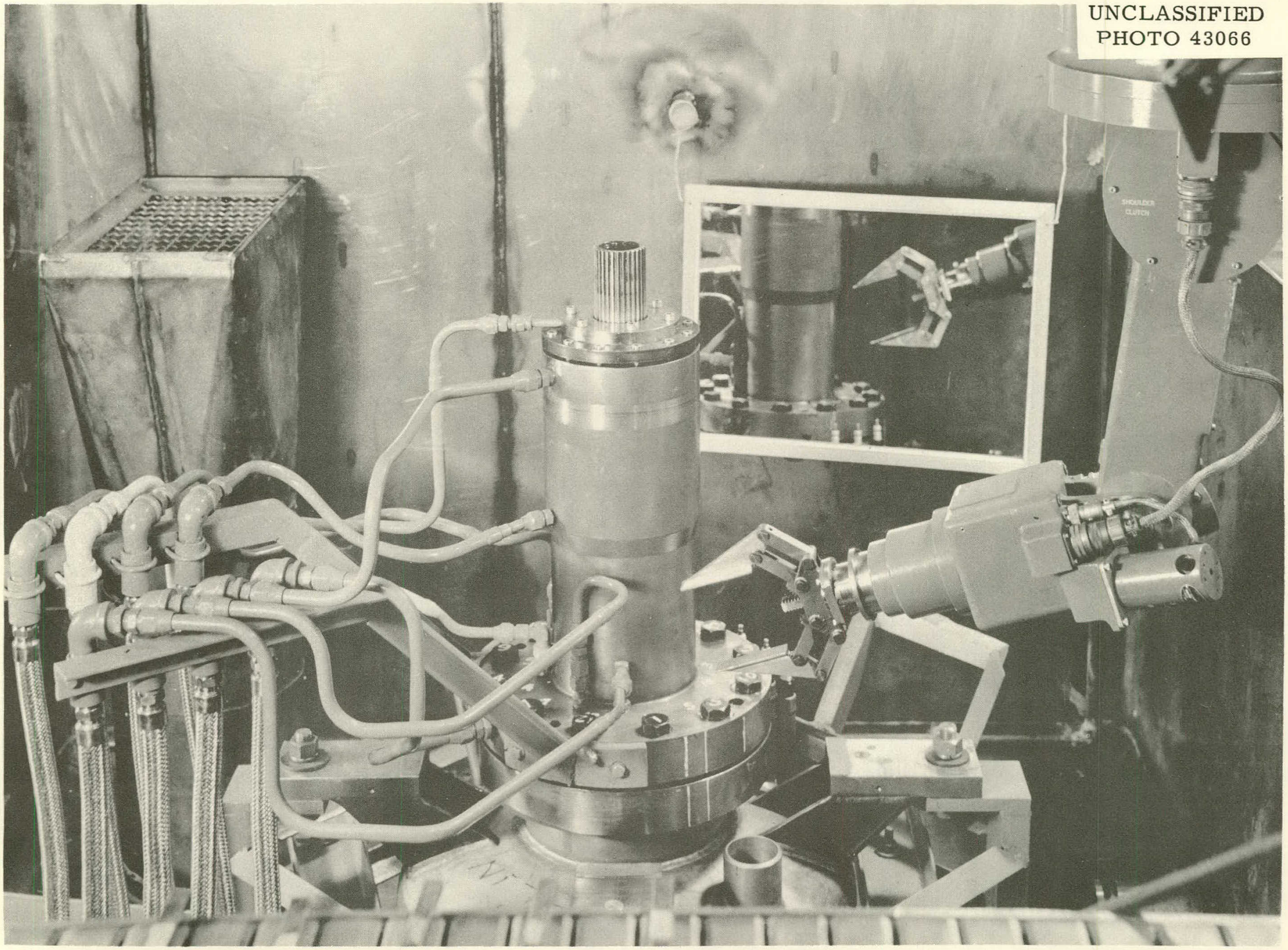

Figure 4 View of Pump Through Cell Window

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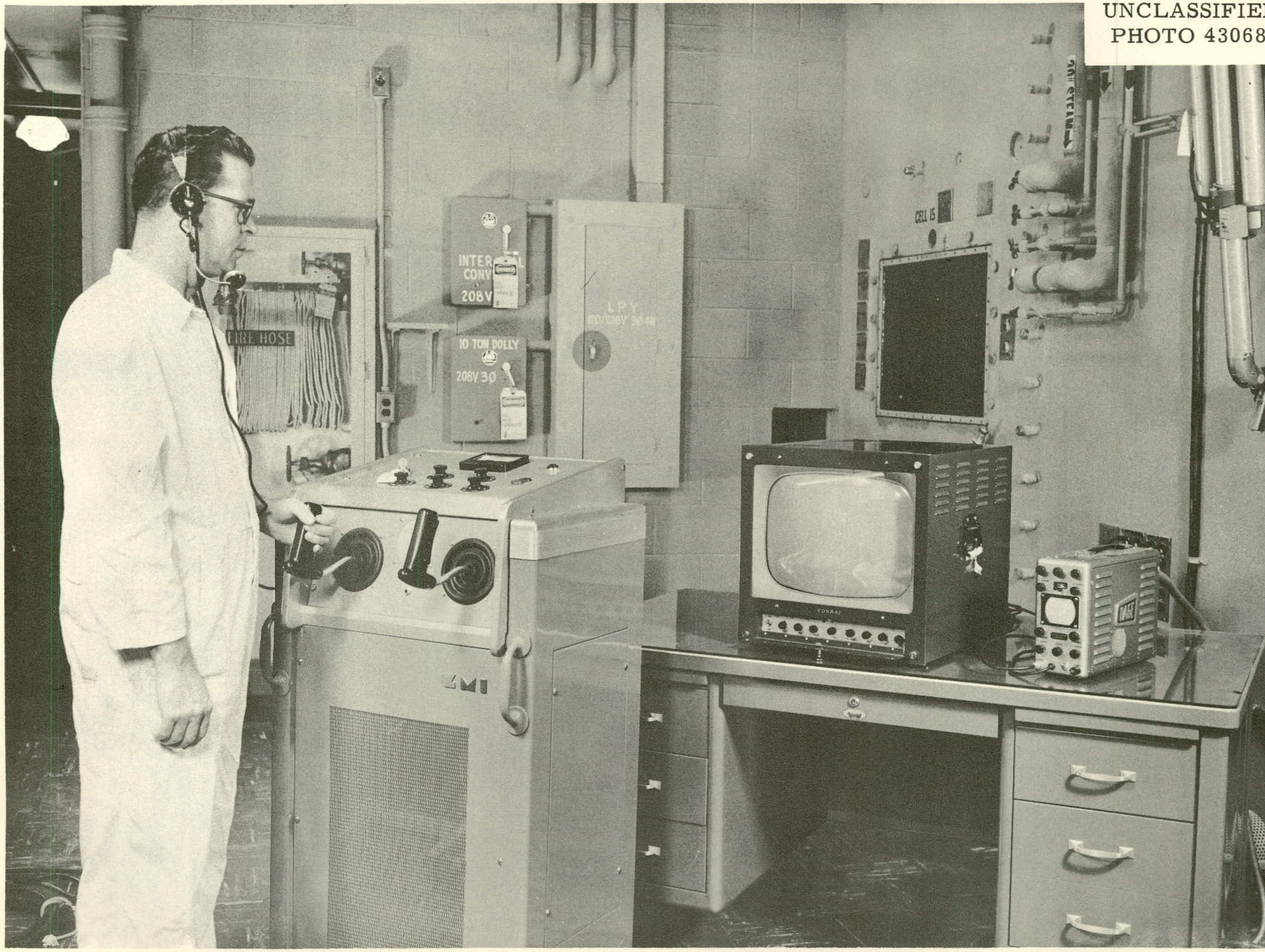

Figure 5 Viewing Manipulator Operations by Television

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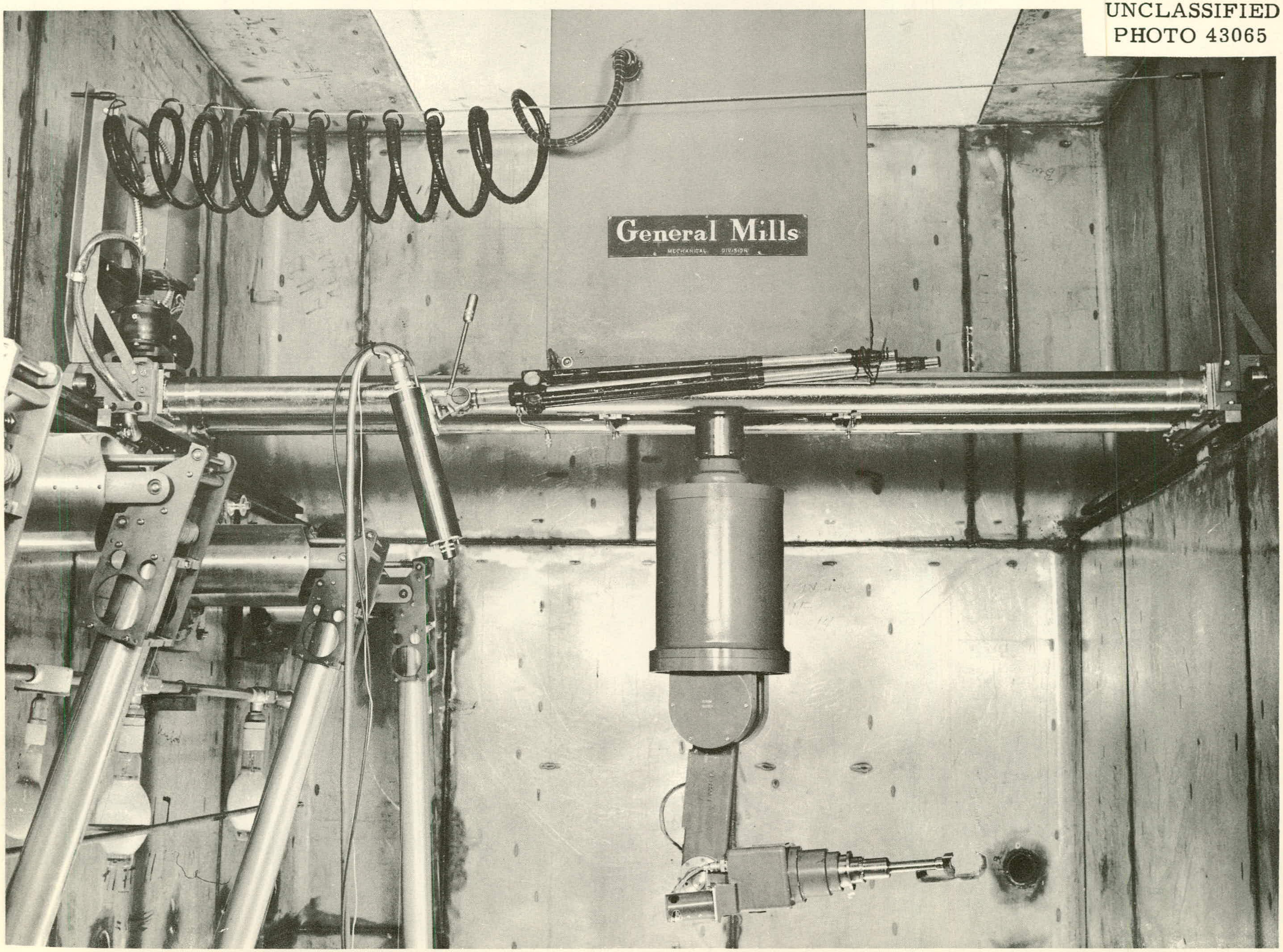

Figure 6 Television Camera Mounted on Manipulator

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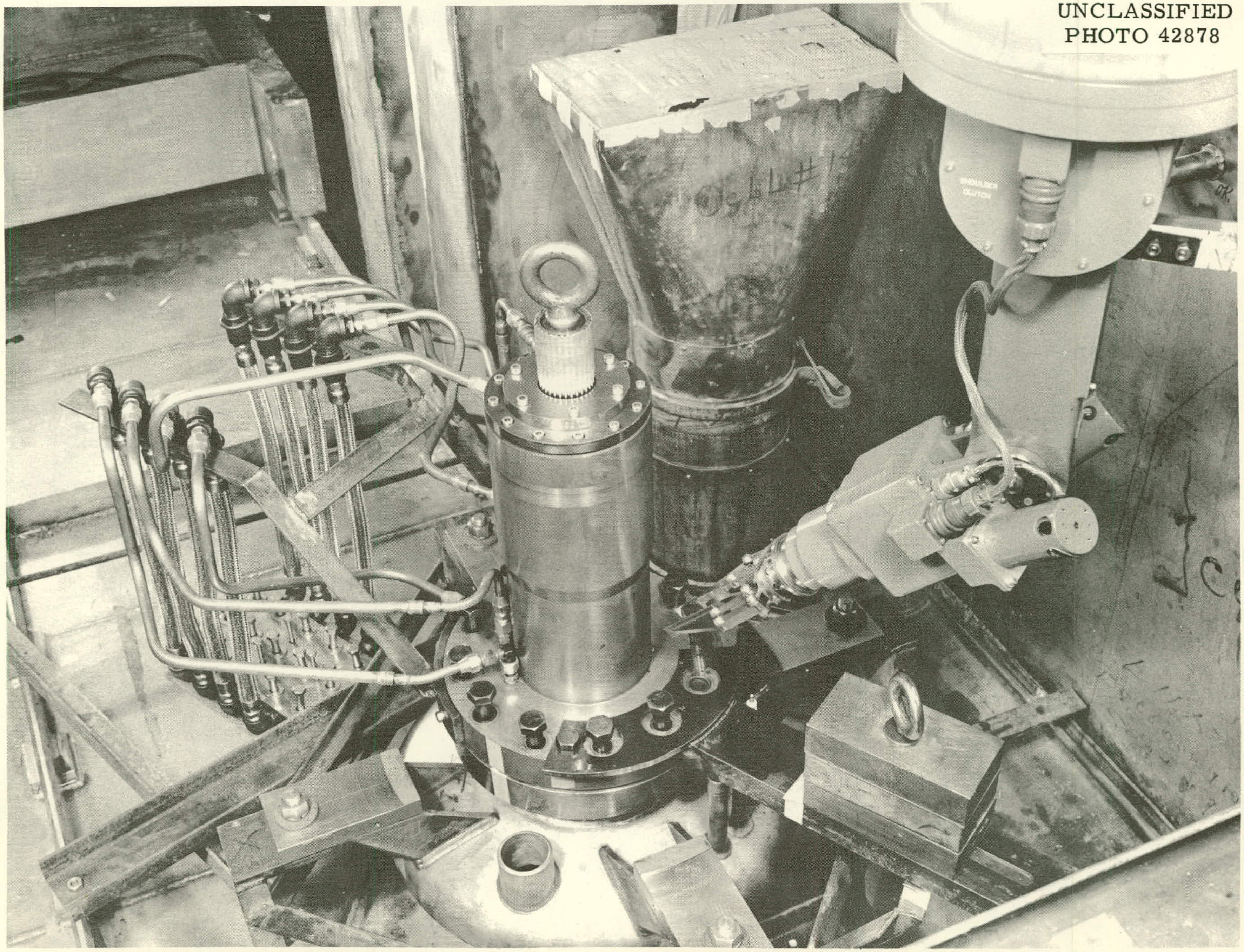

Figure 7 Model PK Molten Salt Pump

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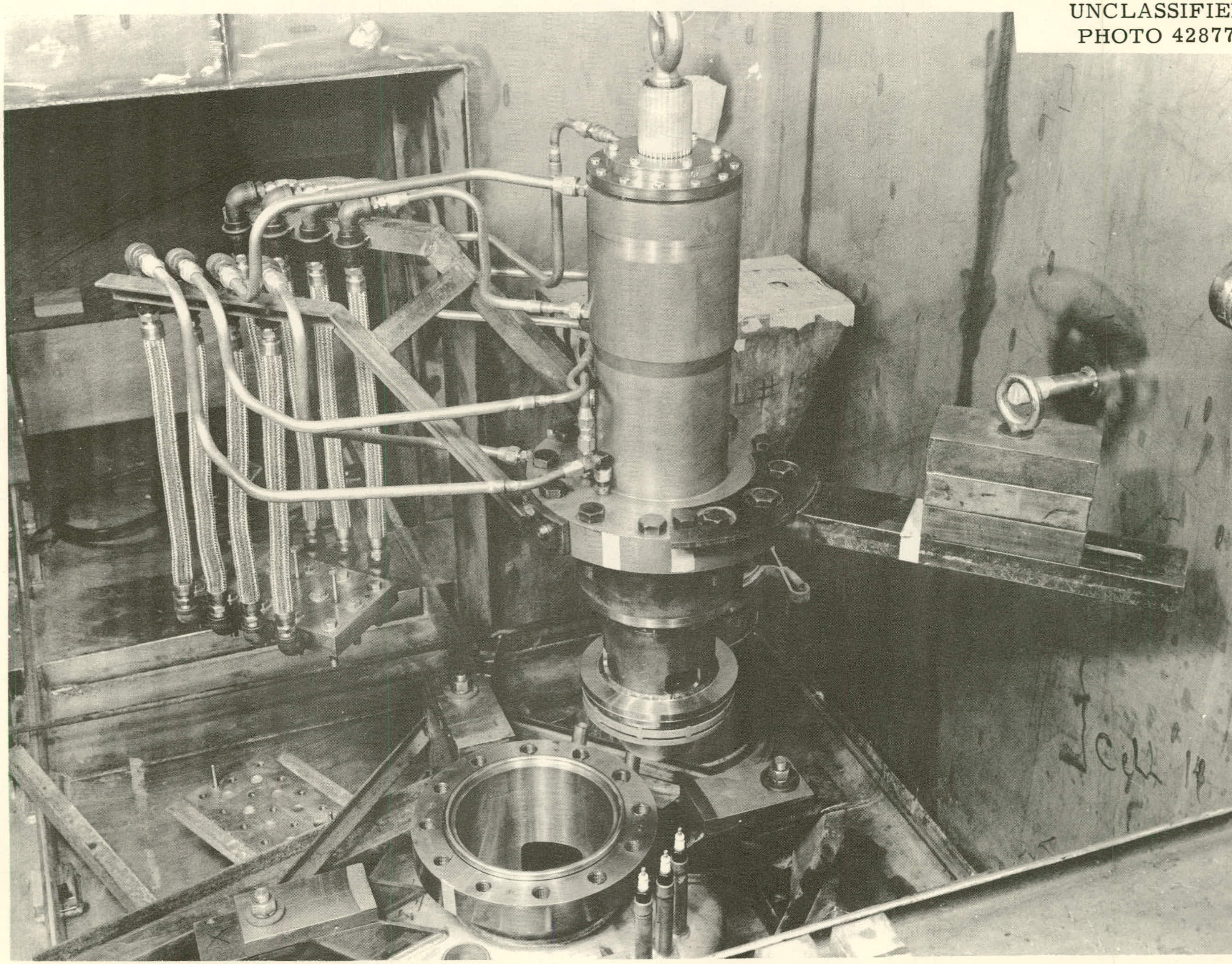

Figure 8 Model PK Molten Salt Pump with En Bloc Service Line Connections

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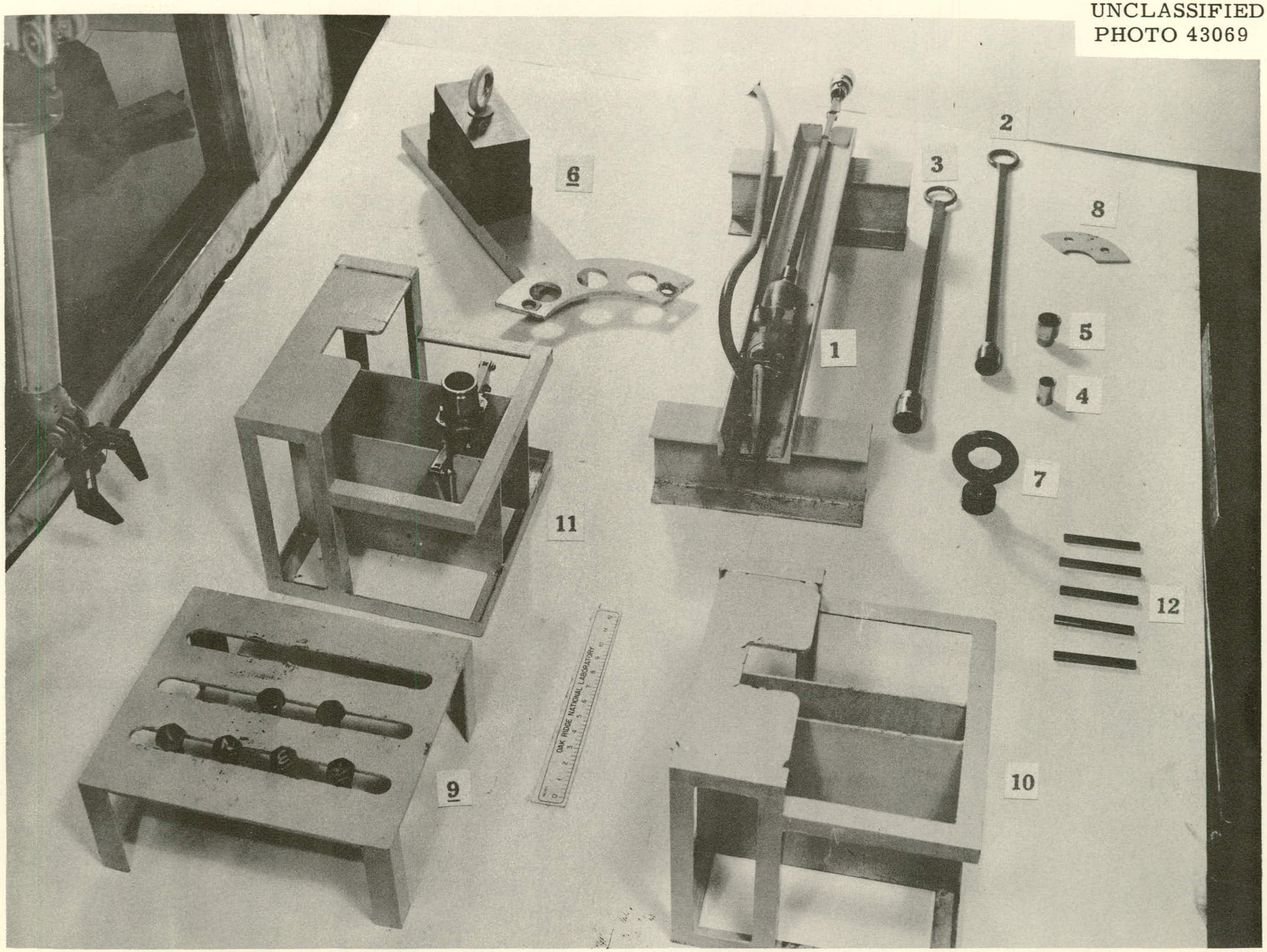

Figure 9 Jigs and Fixtures used with the GM Manipulators

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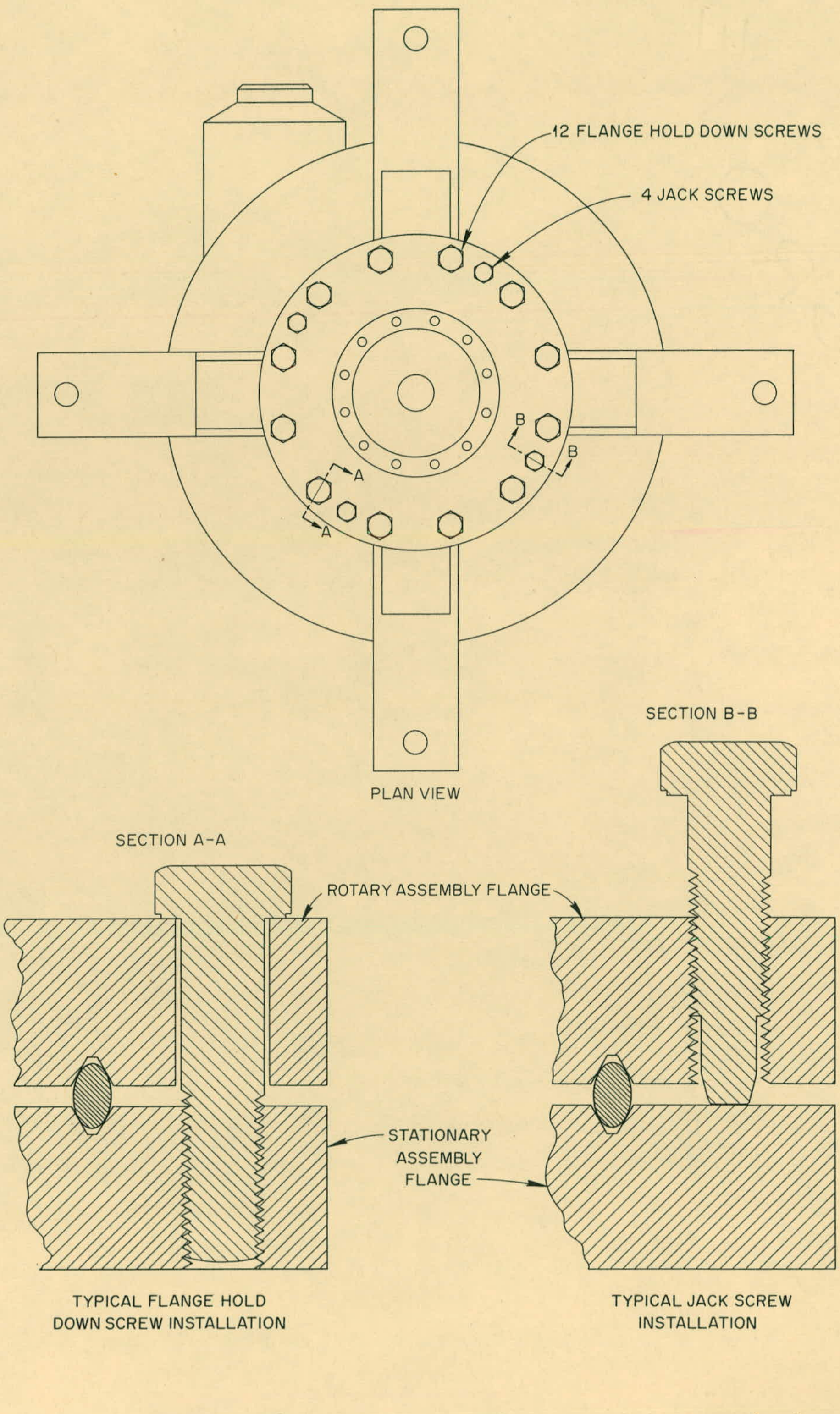

Figure 10 PK Pump Flange Bolting Method